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GENERAL REVIEW OF THE SEISMIC HAZARD  
TO SELECTED U.S. NAVY INSTALLATIONS

H. Bolton Seed, et al

California Institute of Technology

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H. B. Seed, Editor (Prof. of Civil Engineering, U. Cal., Berkeley); C. R. Allen (Prof. of Geology & Geophysics, CalTech, Pasadena); P. C. Jennings (Prof. of Applied Mechanics, CalTech, Pasadena); R. L. Wiegel (Prof. of Civil Engineering, U. of Cal., Berkeley)			
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13. ABSTRACT			
<p>This report summarizes the findings of the Natural Hazards Review Panel whose mission it was to investigate the nature and magnitude of the threats posed to Naval bases by earthquakes and earthquake-related natural hazards including tsunamis, seiches (and the accompanying flooding), landslides, mudflows and soil foundation failures which may result from earthquakes.</p> <p>The Panel was comprised of a soils expert who was concerned especially here with the stability/instability of water-saturated marine soils, a seismologist-geologist intimately acquainted with the behavior of earthquakes and their relations to local geologic structure, a tsunami and wave-propagation expert familiar with the behavior of "tidal waves" and the oscillation of enclosed bodies of water such as bays, and a structural engineer familiar with the dynamic response of various types of building structures when subjected to earthquake-induced ground motions. The Report reflects a broad variety of expertise and emphasizes the broad range of problems which can be recognized only by approaching the problems from a multidisciplinary viewpoint.</p> <p>In addition to citing specific problems for Naval bases in the San Francisco, San Diego and the Manila areas, the introduction to this report recommends conducting a rapid visual survey initially to pinpoint the nature of various danger areas. It then recommends the follow-on procedure leading to various strategic and engineering decisions which will provide the required degree of protection to insure Fleet Operational Readiness and to provide cost effectiveness in protecting the Navy against serious earthquake damage.</p>			

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1 January 1974

GENERAL REVIEW OF THE SEISMIC HAZARD TO  
SELECTED U. S. NAVY INSTALLATIONS  
by the  
ONR NATURAL HAZARDS REVIEW PANEL

Panel Members:

Professor H. Bolton Seed, Department of Civil  
Engineering (U. Cal., Berkeley), Chairman

Professor C. R. Allen, Department of Geological  
Sciences (CalTech, Pasadena)

Professor P. C. Jennings, Department of Mechanical  
Engineering and Applied Sciences (CalTech, Pasadena)

Professor R. L. Wiegel, Department of Civil  
Engineering (U. of Cal., Berkeley)

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Subj: ONR Natural Hazards Review Panel Report "General Review  
of the Seismic Hazard to Selected U. S. Navy Installations";  
Introductory Statement

Encl: (1) Subj Report

1. The ONR Hazards Review Panel was established to evaluate the threat to Naval bases from the earthquake family of natural hazards, including the effects of tsunamis, seiches, landslides, water damage and soil foundation failures, in addition to the effects of shaking due to earthquake generated ground shaking.

2. Enclosure (1) summarizes the findings of the ONR Panel and is broken into six sections:

I. Summary Section

A. GENERAL OBSERVATIONS (a summary statement of findings)

B. RECOMMENDATIONS

(1) Comprehensive Survey of Pacific Naval Bases

Stage I - Visual survey by 2 or 3 specialists  
to pinpoint risk areas.

Stage II - Decision Analysis

Stage III - Engineering Modifications

Stage IV - Operational Contingency Plans

(2) Design Manual Changes

C. RESEARCH RECOMMENDATIONS

Followed by Summaries of Observations and Recommendations at Naval bases  
studied by the Panel:

- II. Naval Air Station Alameda
- III. Naval Air Station North Island
- IV. San Francisco Bay Area Naval Facilities
- V. Naval Weapons Station Concord and Naval Security Group Skaggs Island
- VI. Naval Station Subic Bay

3. Earthquakes are catastrophic events with relatively long periods of intervening quiescence. This creates a false sense of security and psychologically tends to minimize the ever present threat from earthquakes. The following report prepared by the ONR "Earthquake Panel" provides an initial picture of the magnitude of the problem. It is the stimulus from which further quantitative studies will be launched. It provides guidance on what to look for and how to proceed on an efficient basis to solve the problem on a broad scale and in a cost-effective way.

4. The Nation has a considerable investment in Naval bases, and these are necessarily located on unstable marine soils in the worst possible places from the viewpoint of sustaining structural damage from earthquakes in areas which are seismically active. Just as the State of California has increased the structural requirements in its building codes to counter the earthquake threat, it is critically important for Navy to recognize these same hazards in order to insure Fleet Operational Readiness and to initiate construction procedures which will prove Cost Effective against earthquake damage.

5. Enclosure (1) is commended to you for careful reading. It contains the insight of four outstanding specialists in their particular areas of expertise. This report emphasizes technical matters which are not normally considered by the engineer and which must be read from the viewpoint of the numerous disciplines involved.

6. Panel Members include:

Professor H. Bolton Seed, Panel Chairman, former Chairman, Dept. of Civil Engineering, U. of Calif. (Berkeley); Specialist in the dynamic properties of soils, soil fluidization and soil instabilities, etc.

Professor C. R. Allen, CalTech (Pasadena); Seismologist, Geologist (President, Geological Society of America); Expert on the seismicity of S. California and its relation to geologic structure.

Professor Paul C. Jennings, CalTech (Pasadena); has been a member, Board of Directors, Earthquake Engineering Research Institute and of the Applied Technology Council of the Structural Engineers Association of California; and he is an expert on the dynamic response and structural integrity of buildings subjected to earthquake motions.

Professor Robert L. Wiegel, formerly Dean of Engineering,  
U. of Calif. (Berkeley); Expert on tsunamis, wave propagation,  
seiche motion, hydrodynamics and the effects of resulting  
flooding and structural damage.

*John G. Heacock*

JOHN G. HEACOCK  
Director, Earth Physics Program  
Code 463



FEB 04 1974

H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

December 30, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

During the past eight months the ONR Natural Hazards Review Panel consisting of Professors C. R. Allen, P. C. Jennings, R. L. Wiegel and H. Bolton Seed has conducted a general review of the seismic hazard to U. S. Navy installations at Alameda Naval Air Station, Concord Naval Weapons Center and Skaggs Island in the San Francisco Bay Area, North Island N.A.S. in San Diego, and Subic Bay Naval Station in the Philippines. Our specific findings for each of these installations have been presented in the attached series of letter reports. During the course of these site evaluations, a number of general observations and recommendations have emerged, together with suggested areas of research which the Navy might follow to help minimize the potential earthquake damage at its installations, and it seems desirable to set these down in a separate report. Most of the ideas have been transmitted to you during the course of our site visits but we present them again in the following pages as a formal record of our views.

General Observations

1. As a matter of necessity, Naval bases and installations are invariably located in low-lying coastal areas where local soil conditions often consist of saturated sands and soft clays. It also appears that substantial areas of the installations consist of land reclaimed by filling with locally available sand and clay

deposits. Such areas are particularly vulnerable to the following effects of earthquakes:

- (1) flooding due to subsidence or tectonic land movements
- (2) flooding due to tsunamis or seiches
- (3) liquefaction of loose sand deposits with associated deformations of structures located on them
- (4) landslides
- (5) lurching and weaving of soft clay deposits
- (6) large amplitude shaking which can be particularly damaging to long period structures.

While such effects are sometimes encountered in other design and construction projects, they are relatively rare compared with their prevalence at Navy installations. Thus the protection of Navy installations against seismic hazards must pay more attention to unstable soil conditions than is normally the case.

2. Associated with the need to locate Naval facilities in low-lying areas, facilities are sometimes located on land areas below sea level which are protected by dikes of uncertain or unknown composition. Such areas are especially vulnerable to flooding caused by dike slumping or failure during strong earthquake shaking.
3. Seismic design criteria for structures at Navy installations are generally similar to those of the Uniform Building Code and it is important to recognize that:
  - (1) It is the intent of such code provisions to protect structures from collapse during major earthquakes, but not necessarily to prevent serious damage, especially to non-structural components such as lighting, partitions, ceilings, mechanical equipment, etc.
  - (2) Current seismic design criteria and practices may not be providing the level of protection that the Navy may require for structures of critical importance.
  - (3) Current seismic design criteria do not protect structures against the various types of earthquake-induced soil

instability which are likely to be encountered at Naval installations.

- (4) Current seismic design criteria make no provisions for ensuring the integrity of water supply, power supply and other services which may be essential for operation of a Naval base following an earthquake.
4. Damage to civilian communities resulting from a major earthquake such as may occur in California is potentially so great that the Military Services will be called upon to take a leading role in the civilian relief operations. Thus it may well be desirable for major military bases adjacent to metropolitan centers to be designed to earthquake-resistant standards that are considerably higher than those required for ordinary structures and facilities.
5. In general it appears that insufficient attention has been paid to ensuring the operational capability of Navy bases and installations following major earthquakes of the type which may occur along the Pacific coast. Facilities have been constructed on potentially unstable soils, design criteria do not necessarily ensure operational ability, and some facilities may well be inundated due to dike failures or tsunamis. Such risks may well be justified but they should only be taken with full awareness of the problems and the potential consequences.

#### Recommendations

1. In view of the seismic hazards to Navy installations disclosed by the Panel evaluations of facilities at Alameda N.A.S., North Island N.A.S., Skaggs Island and Subic Bay as well as the hazard potential indicated for other bases in the San Francisco Bay Area, it is recommended that the Navy make a comprehensive survey of the seismic hazards for all bases in the Pacific area to determine the possible extent of damage which may occur during earthquakes and the effect of such damage on operational capability, and the ability of the Navy to respond to civilian needs in the event of a major disaster.

We visualize that the survey would be made in a series of stages:

Stage I - Evaluations of the hazard potential for all Navy bases and installations through a study of available information and visual inspection of the facilities in a manner similar to that used by the Panel for Alameda and North Beach N.A.S. Such evaluations might be made by a team composed of two or three specialists in earthquake engineering supported by Navy base engineering personnel. One of the specialists should be a structural engineer experienced in evaluating the dynamic response of structures to expected earthquake motions and the extent of damage they may sustain including non-structural damage and damage to equipment. Another should be a soil and foundation engineer experienced in evaluating the response of soils to earthquake motions including the possibility of settlement, liquefaction and landslides and with the damaging effects of earthquakes on docks, quay walls, underground utilities and building foundations. At some bases, an ocean engineer, experienced in evaluating ocean-related problems should be part of the team. In addition to evaluating the extent of damage to the Navy facilities, the team should also consider the possible effects of earthquake damage to civil works on Naval operations.

Stage II - Evaluate the results of the surveys in Stage I to determine the impact of a major earthquake on individual bases and on groups of bases which may be affected by the same event. Decisions could then be made on such matters as

- (1) the acceptability of the hazard potential from the point of view of national security, continued operations, etc.
- (2) alternative operational plans if certain facilities are non-functional
- (3) designation of critical facilities from an operational point of view

- (4) designation of those structures and facilities whose earthquake resistance should be evaluated in greater detail than that warranted in the initial survey.

Stage III - Strengthening and modification of critical structures.

Working with a priority list, structures deemed by the Navy to be so important that they must survive strong ground shaking without loss of function should be studied in detail and strengthened accordingly; in addition to the structure, attention should be given to non-structural features, utilities and standby-power sources.

Stage IV - Development of contingency plans, and plans for reducing the earthquake hazard to Navy Installations to an acceptable level.

2. The Design Manual used for seismic design of Navy facilities should be reviewed to ensure that
  - (1) appropriate consideration is given to ensuring the stability of soils during earthquake shaking
  - (2) the design criteria are capable of providing the level of protection required for Navy facilities in view of the special roles of the Navy in National Defense and possibly in disaster relief operations
  - (3) appropriate consideration is given to ensuring the integrity of water supply, power supply and other services which may be essential to operation of a Naval base.
3. Typical storage tanks of the type usually used for petroleum products have been seriously damaged in a number of recent earthquakes and in some cases have caused major fire hazards. All such tanks should be checked to see if they can survive strong shaking without rupture and consequent fire hazard.
4. Fire-fighting equipment including water tanks and building structures should be checked to ensure that they can withstand a major earthquake without loss of function and preventive measures should be taken,

where necessary, to ensure that rupture of water lines does not cause loss of fire-fighting ability.

Recommendations for Research

1. The possible presence of a major active fault directly beneath San Diego Bay is of such critical importance to the Navy that ONR should initiate a detailed study of this possibility. Furthermore, the importance of this Navy base is so great, and an understanding of the tectonics and seismicity of this region is so small, that it is the logical focus of other ONR earthquake-related research efforts. For example, the Panel hopes that the ONR can continue to support the telemetered seismic network in this region, to build up the knowledge of regional seismicity that is fundamental to estimating and understanding the seismic risks.
2. Many Naval facilities are located on filled land or on deposits of soft clay or loose sand. There is a great lack of recorded strong earthquake motions at such sites and the Navy should install strong motion instruments at a number of such sites in seismic areas so that the probable character of shaking in future earthquakes can be better assessed.
3. Since it appears that earthquake-induced soil liquefaction and movements of soft clays are potentially a major hazard at many Naval installations, the Navy should support research to better define (1) the conditions under which liquefaction may occur and the extent of resulting ground movements and (2) the deformation potential of soft clay deposits under seismic loading conditions.
4. Some structures built by the Navy are sufficiently different from civilian structures that their dynamic properties (periods, modes, damping) cannot be confirmed by measurements of structural response obtained in buildings during earthquakes. A number of such structures, including control towers, hangars, dry docks, etc., should be instrumented so that more information on their dynamic characteristics can be obtained.

Mr. John G. Heacock  
December 30, 1973  
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5. The Navy should develop improved procedures for evaluating the effects of tsunamis at critical bases such as San Diego and San Francisco, including the effects of tsunami-generated currents and their effects on ship moorings. Particular attention should be given to tsunami wave periods and heights associated with vertical displacements on off-shore faults, such as may occur off-shore from San Diego.
6. Since the draw-down of a tsunami is equal to its run-up, the Navy should study the effect of draw-downs on a moored ship striking bottom, and on waterfront facilities such as quay walls whose stability might be affected by loss of hydrostatic pressures on the water side of the structure.

Very truly yours,

C. R. Allen  
P. C. Jennings  
R. L. Wiegel  
H. Bolton Seed, Chairman

HBS/nh

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H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

June 13, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

On May 3, 1973 an Advisory Panel consisting of Professors Clarence R. Allen, Paul C. Jennings, Robert L. Wiegel and myself visited the Alameda Naval Air Station, California to make a preliminary assessment of the potential damage which might occur to the facility in the event of a major earthquake in the San Francisco Bay Area and formulate general recommendations for research which should desirably be conducted by the Navy to minimize the potential hazards. The inspection consisted of a briefing followed by a bus and walking tour of some typical structures and facilities.

On the basis of such a brief inspection it is only possible to form general impressions on many aspects of the hazard potential and specific recommendations concerning individual structures and areas would require more detailed study. However our general impressions and recommendations resulting from the inspection are presented below:

General Impressions and Conclusions

1. There is no evidence that the station is directly underlain by faults which might cause a problem either in terms of large earthquakes or in terms of surface displacement and the seismic hazard at the Station is determined primarily by possible earthquakes generated by the San Andreas fault, some 12 miles to the west and by the Hayward and associated faults, the closest of which is some



7 miles to the east. Possible earthquakes on these faults might be expected to occur with the following approximate frequencies:

<u>San Andreas Fault</u>		<u>Hayward &amp; Calaveras Fault System</u>	
<u>Magnitude</u>	<u>Recurrence Interval</u>	<u>Magnitude</u>	<u>Recurrence Interval</u>
8.3	≈ 200 years	7.5	≈ 500 years
8.0	100 to 200 years	7.0	100 to 500 years
7.5	60 to 150 years	6.5	50 to 100 years
7.0	50 to 100 years		

2. The greater portion of the Alameda Naval Air Station is constructed on a fill of loose to medium dense sand overlying soft clay (San Francisco Bay mud). The general characteristics of the sand are similar to those of sands which are known to have liquefied at other locations during strong earthquake shaking and it therefore seems likely that liquefaction could occur under many parts of the base in the event of the earthquakes discussed above; these areas would probably include the airfield and runways as well as built-up areas.

While it does not seem likely that liquefaction would lead to major slides, it could well lead in some areas to lateral displacements of the ground measured in numbers of feet, with accompanying settlements of buildings, shifting of foundations, disruption of utilities and runways, slumping of breakwaters and outward movements of piers and quay walls. While such movements might not be catastrophic they could easily prevent the continued functioning of the base until extensive repair work had been completed.

3. The existing building structures, including hangars, offices, warehouses and barracks are not of types generally considered to be especially hazardous during strong earthquake motions. Thus, even in a large earthquake, it is expected that major structural failures or collapses from shaking would be the exception, rather than the rule.

4. Although most buildings are expected to survive strong shaking without significant structural damage, most buildings probably would not be functional immediately after an earthquake because of nonstructural damage to light fixtures, ceilings, partitions, mechanical equipment, storage racks, etc. In addition, localized soil deformation and settlements quite probably would rupture underground utility lines, leaving many structures temporarily out of water, sewerage service, and possibly electrical service.

The warehouses (not visited) may pose special difficulties from such effects as toppled storage racks, damage to pendant light fixtures, possible release of flammable or toxic substances, etc.

For more information about possible occurrence of non-structural damage, reference is made to "Nonstructural Damage to Buildings," by J. Marx Ayres, Tseng-yao Sun and Frederick R. Brown, in The Great Alaska Earthquake of 1964 - Engineering, Publication 1606, National Academy of Sciences, Washington, D. C., 1972.

5. It should be realized that existing building codes and practices are not capable of insuring the level of protection that the Navy may want for certain facilities at the Air Station that are of critical importance to the operation. Without a detailed investigation, it cannot be assumed that any individual structure will survive strong shaking without serious structural damage or loss of function through nonstructural damage.
6. A portion of the Alameda NAS could be inundated by a tsunami and the accompanying drawdown could lead to moored slips striking bottom or failure of quay walls due to differential hydraulic pressures.
7. The potential impact of the above effects on Naval operations can only be evaluated by Naval authorities. However in making this evaluation it should be noted that the damage to adjacent communities resulting from the occurrence of the stronger earthquakes discussed

in (1) above, is potentially so great that the nation's Armed Forces are likely to be called upon to take a leading role in the civilian relief operations. For this reason, it might well be desirable for major military bases, particularly those close to metropolitan centers, to be designed to earthquake-resistant standards that are considerably higher than those required for most ordinary structures and facilities.

The 1964 Alaskan earthquake provides a good example of a situation in which the Armed Forces were immediately placed in a position of emergency leadership and they could well have been embarrassed if large portions of their operations, particularly those related to aircraft, had been put completely out of action by the earthquake. In this regard it should be kept in mind that it is more critical for some structures to survive an earthquake in a "functioning status" than others; included in this group should be fire-fighting facilities, communication centers, control tower, etc.

#### Recommendations

1. Fire-fighting equipment, including water tanks and building structures, should be checked to insure that they can survive a major earthquake without loss of function. In particular preventive measures may be needed to make certain that rupture of waterlines does not cause loss of fire-fighting capability.
2. Any structure deemed by the Navy to be so important that it must survive strong ground shaking without loss of function should be studied in detail. In addition to the structure, particular attention must be given to nonstructural features, utilities, and standby power.
3. Typical storage tanks of the type usually used for petroleum products have been seriously damaged in many recent earthquakes. Any such storage tanks on the Station should be checked to see if they can survive strong shaking without rupture and consequent fire hazard.

4. Many Naval facilities are on filled ground or on natural saturated sediments near bodies of water. There is a great lack of recorded strong earthquake motions on such sites, and it is recommended that the Navy Install strong-motion instruments at several sites in seismic areas so the character of shaking in future earthquakes can be determined.
5. Some structures built by the Navy are sufficiently different from civilian structures that their dynamic properties (periods, modes, damping) cannot be confirmed by measurements of structural response obtained in buildings during earthquakes. It is recommended that a few typical or important structures be instrumented with strong-motion instruments so that assumed or calculated dynamic properties can be confirmed by measurements. Examples might include control towers, storage facilities, hangars, drydocks, or off-loading installations.
6. The liquefaction potential of the soils in critical areas of the Alameda N.A.S. should be carefully evaluated to determine the extent of the hazard due to this cause. In addition, since it is likely to be a major seismic hazard at many Naval installations, the Navy should support research to better define the conditions under which liquefaction can occur and the extent of resulting ground movements.
7. In terms of the continued operation of the Alameda N.A.S. following a major earthquake, it might be well to consider the possibility that the harbor might be blocked by collapse of the Bay Bridge. While this might not be a problem at all and the bridge is clearly not the Navy's responsibility, it would seem to be desirable for the Navy to ascertain whether such an event would pose a problem for its own ships. It would seem desirable that the Navy should stimulate appropriate civilian authorities to make an engineering study of the earthquake resistance of the bridge.

Mr. John G. Heacock  
June 13, 1973  
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8. A map was issued in 1972 by the U. S. Geological Survey showing "Areas of Potential Inundation by Tsunamis in the San Francisco Bay Region, California," (J. R. Ritter and W. R. Dupre, Miscellaneous Field Studies Map MF-480). While the information presented on this map should be examined critically, and not used directly for planning purposes by the Navy for the Alameda N.A.S., a study should be made to determine the probability of tsunami run-up that might occur, together with the probability of occurrence of astronomical and meteorological tides. The study should include an investigation of the effect of different values of run-up on the operation of the facility and give consideration to the effectiveness of the Tsunami Warning System that exists for the Pacific Ocean area.

During the 1964 Alaska earthquake and tsunami, the run-up in San Francisco Bay was of minor importance. However, the tsunami produced substantial currents in some areas, causing some small craft to break their mooring lines with resulting damage. An investigation should be made of the effect of these currents on moored aircraft carriers.

Most studies of the effects of tsunamis have been in regard to run-up and currents. However, the "draw-down" of a tsunami is equal to its run-up. The Navy should study the effect of different probable "draw-downs" on a moored ship striking bottom, and on water front facilities, such as quay walls, whose stability could be impaired by the reduction in hydrostatic force acting on the bay side of the structure.

We trust these observations will be helpful to your evaluation program.

Very truly yours,

C. R. Allen  
P. C. Jennings  
R. L. Wiegel  
H. Bolton Seed, Chairman

HBS/nh

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H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

November 1, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

On July 26, the ONR Natural Hazards Review Panel consisting of Professors Clarence R. Allen, Paul C. Jennings, Robert L. Wiegel and myself, visited the North Island Naval Air Station in San Diego, California to make a preliminary assessment of the potential damage which might occur to the facility in the event of a major earthquake in the San Diego area, and to formulate general recommendations for research which should desirably be conducted by the Navy to minimize potential seismic hazards. The inspection consisted of a briefing, followed by a car and walking tour of some typical structures and facilities.

On the basis of such a brief inspection it is only possible to form general impressions on many aspects of the hazard potential, and specific recommendations concerning individual structures would require more detailed study. However our general impressions and recommendations resulting from the inspection, together with other knowledge of the seismic hazards in San Diego, are presented below:

#### Geology and Seismicity

There is a feeling in some quarters that earthquake hazards in San Diego are considerably less severe than in other areas of California such as Los Angeles and San Francisco. There are several reasons for this apparent complacency, all of which need critical re-examination.

San Diego has never experienced in recent years a really damaging earthquake comparable to those that have hit parts of the other major metropolitan areas of the state. Most people have long forgotten major shaking associated with such shocks as that of 1892 (Intensity VII in San Diego). Seismologists now recognize that our short historic record in California is not a valid guide for estimating long-term seismicity, and the absence of major earthquakes in San Diego during the past 100 years is not necessarily a cause for great comfort for the future. Many people have referred to Allen et al. (1965) in pointing out that the San Diego block appears geologically and seismically stable as compared to adjoining blocks, although Allen et al. (1965) went on to emphasize that, even in the absence of numerous active faults in the San Diego area itself, nearby seismicity was sufficiently high so that seismic hazard from shaking in San Diego was probably not grossly different from that in most parts of Southern California. However, even the conclusion of Allen et al. (1965) concerning the relative geologic stability of the San Diego block itself has been shown in recent years to be at least partially incorrect. For example, numerous breaks of late Quaternary age have now been documented by Artin and Pinckney (1973), Ziony and Buchanan (1972) and Moore (1973). Furthermore, it has been claimed that the Newport-Inglewood fault (locus of the 1933 Long Beach earthquake) is continuous with the Rose Canyon fault in La Jolla, and thence continues south through San Diego Bay and into Mexico (Wiegand, 1970; Moore and Kennedy, 1970). This extrapolation seems to be a matter of some controversy, but its significance is very great; a fault of this length and continuity could presumably generate a large earthquake squarely within the San Diego metropolitan area, with possible faulting directly through the Coronado bridge. Brune (1972) feels that a magnitude 6-1/2 earthquake within the San Diego area is a "risk that must be considered in conjunction with the risk from the possibility of moderate and large earthquakes at some distance".

Brune (1972) and McKuen and Pickney (1972) have recently attempted to evaluate seismic risk in the San Diego area, and their papers should be read by interested parties. Based upon their work, as well as that

of a number of other workers, our preliminary evaluation is as follows:

Although numerous Holocene faults have now been recognized in the San Diego area, neither their lengths nor their apparent degrees of activity suggest that they are as pertinent to the evaluation of seismic hazard as are the offshore faults to the southwest, and the members of the San Andreas system to the northeast. Ziony and Buchanan (1972), for example, state that along both the Rose Canyon (Newport-Inglewood?) and La Nacion faults, topographic features such as sag ponds or well-defined scarps, which are commonly associated with Holocene faulting elsewhere in Southern California, have not been observed. Furthermore there is considerable doubt concerning the continuity of the Newport-Inglewood fault through the San Diego Bay area and into Mexico, although assuredly this question is so important that the Navy--of all groups--should be supporting research work to demonstrate its presence or absence.

Of perhaps greatest concern in a practical sense are the faults offshore from San Diego to the southwest. The Coronado escarpment, 25 km southwest of North Island, is one of the major fault-produced escarpments of the continental borderland (Emery, 1960; Moore, 1969), and it is probably a continuous feature with the Agua Blanca fault of Baja California (Allen, Silver, Stehli, 1960). The Agua Blanca fault shows fresh topographic features of faulting comparable to those of the San Andreas, and it is a likely locus of the 1892 earthquake ( $M = 7-1/2+$ ). Furthermore, the offshore area near the Coronado escarpment has been a region of moderate seismic activity over the years, and gradual improvements in our seismic networks (such as those now being supported in this area by the ONR) will help to pinpoint the specific active features. Even farther offshore is the San Clemente Island fault zone, which is 65 km southwest of North Island. A magnitude 5.9 shock occurred on this fault near San Clemente Island in 1951. Certainly a shock of magnitude 7 is a reasonable event on either of these faults. McEuen and Pinckney (1972) assign a magnitude of 7.7 to the "maximum



credible earthquake" on the San Clemente Island fault. The assignment of a specific probability to such an event, however, is beyond our capabilities at the present time; any estimate based on recorded seismicity during the past 40 years would be founded on such minimal statistics as to be almost meaningless. An educated guess--based on the regional geology and its comparison with other similar areas--would indicate that a magnitude 7 earthquake might occur on one of these two faults in the area opposite San Diego perhaps once every 200 years.

Also of significance to the seismicity of the San Diego area are the active faults of the San Andreas system to the northeast, the closest principal branch of which is the Elsinore fault at a distance of 65 km. A magnitude 6 earthquake in 1910 was probably centered on the Elsinore fault, but in general, it does not appear as active either geologically or seismically as is the San Jacinto fault still farther east. Earthquakes similar in magnitude to those on the off-shore system are certainly possible, but it seems likely that the off-shore faults are more active. In a recent evaluation of the seismicity of the Mt. Palomar Observatory area (70 km northeast of San Diego and 7 km east of the Elsinore fault), Allen and Hanks (1973) estimated that a magnitude 7+ earthquake might occur within 50 km of the Observatory once every 140 years, but the chances are higher that this earthquake would be east of the Observatory (on the Agua Tibia, Agua Caliente, or San Jacinto faults) rather than on the Elsinore fault itself. Major earthquakes on the San Jacinto fault zone occur rather frequently, but its distance from San Diego (100 km) is sufficiently great that closer but less frequent shocks are probably of greater design importance for critical structures in San Diego. McEwen and Pinckney (1970) calculate that the maximum probable earthquake on the Elsinore fault in a 60-year period is a magnitude 7.3 event, although this is questionable since it is based on an extrapolation from the far-more-active Imperial Valley area.

General Impressions and Conclusions

1. On the basis of the preceding review of the geology and seismicity of the San Diego area, it seems reasonable to believe that the effects of the following types of earthquakes should be considered in the design of important engineering facilities in the area:

- (a) A magnitude 7 shock occurring about 15 miles from San Diego in the Coronado escarpment
- (b) A magnitude 7<sup>+</sup> earthquake occurring on the Elsinore fault
- (c) A magnitude 6-1/2 earthquake occurring within the San Diego area itself.

In addition, there is some possibility of a major fault extending through San Diego Bay.

Such earthquakes could certainly produce potentially destructive ground shaking in the San Diego area. Depending on the circumstances the peak accelerations might be as high as 0.3 to 0.5g.

2. The soil conditions at the Naval Air Station appear to consist primarily of sands to a depth of at least 40 ft. Over a substantial area of the Station (a strip about 300 ft wide along the western boundary adjacent to San Diego Bay, a strip about 800 ft wide along the southern boundary adjacent to the Pacific Ocean, and a strip about 1200 ft wide running south from the carrier docking facilities) the upper layer of sand has been deposited by hydraulic filling operations. This material is in a relatively loose condition and may well be vulnerable to liquefaction under relatively strong earthquake shaking. The natural sands appear to be considerably denser and there is a good possibility that they would not be vulnerable to liquefaction during strong earthquake shaking.

However if the hydraulic sand fill should liquefy during an earthquake, considerable damage to a number of important facilities could occur; these facilities include the carrier docking berths and all structures in the adjacent area to the south, including the fuel storage tank and warehouses, the major tank farm on the western edge of the base, the Navy Lodge, etc. In addition it is important to

note that the main water supply and sewer lines pass through the hydraulic fill area and may well be disrupted by the ground movements in the liquefied sand, leaving most of the base without utility service or water supply.

3. Most of the existing structures such as hangars, offices, quarters and industrial-type buildings are not of types considered to be particularly hazardous in the event of strong earthquake motion. There are two important exceptions to this general observation: the office buildings that were constructed around 1918 and the petroleum storage tanks (above ground) across the entrance channel from the west end of North Island Station. Although the seismic hazard represented by these structures cannot be determined more definitely without detailed studies, the history of earthquake performance of structures of these two types is very poor.
4. Although most buildings are expected to survive strong shaking without significant structural damage, most buildings probably would not be functional immediately after an earthquake because of non-structural damage to light fixtures, ceilings, partitions, mechanical equipment, storage racks, etc. In addition, localized soil deformation and settlements quite probably would rupture underground utility lines, leaving some structures temporarily out of water, sewerage service, and possibly electrical service.

For more information about possible occurrence of nonstructural damage, reference is made to "Nonstructural Damage to Buildings," by J. Marx Ayres, Tseng-yao Sun and Frederick R. Brown, in The Great Alaska Earthquake of 1964 - Engineering, Publication 1606, National Academy of Sciences, Washington, D. C., 1972.

5. It should be realized that existing building codes and practices are not capable of insuring the level of protection that the Navy may want for certain facilities at the station that are of critical importance to the operation. Without a detailed investigation, it cannot be assumed that any individual structure will survive strong shaking without serious structural damage or loss of function through non-structural damage

6. There is a general attitude among engineers in the San Diego area, by no means confined to naval personnel, that the earthquake problem is not very serious. This is especially the case when comparisons are made to the Los Angeles or San Francisco areas. For this, and perhaps other reasons, we received the general impression that, even though the Navy has an enormous capital investment in facilities in the San Diego area, there has been no significant effort to determine the earthquake hazard to this investment. Under such circumstances, if a major earthquake should occur in the San Diego area, it would almost certainly be extremely costly to the Navy.
7. Little is known about the possible run-up due to tsunamis in the San Diego area. However there is a potential for major flooding due to tsunamis and detailed studies of the possible magnitude of these effects should be undertaken.

#### Recommendations

1. The possible presence of a major active fault directly beneath San Diego Bay, as proposed by Wiegand (1970) and by Moore and Kennedy (1970), is of such critical importance to the Navy that the ONR would seem to have an obligation as well as an opportunity to study all possible data on this situation. In particular, it would seem that an intensive program of acoustic reflection profiling within the Bay might well lead to diagnostic evidence supporting or disproving the suggestion. If the fault is indeed present as a continuous feature breaking young sediments, then some major re-appraisals of the safety and effectiveness of Naval facilities in the San Diego area might well be in order.
2. In view of the potentially hazardous consequences of soil liquefaction at the North Island NAS, it would be highly desirable to initiate a detailed study of the liquefaction potential of all the sand deposits underlying the base to determine:

- (1) the possible extent of liquefaction of the sands in the event of a major earthquake as discussed previously
- (2) the structures which could be seriously damaged or rendered inoperable as a result of ground movements due to liquefaction
- (3) the time required to restore critical structures to an operating condition
- and (4) the alternative accommodations available for critical operations while repairs are being made.

Typical examples of specific problem areas include:

- (1) The mooring dock for carriers is adjacent to hydraulic sand fill deposits which could liquefy and cause severe deformations of the dock, and damage to carriers berthed there, during a severe earthquake. Alternative docking and loading points for unaffected carriers should be investigated.
- (2) Any plans to relocate fuel tanks presently on Point Loma to locations on North Island should be reviewed to ensure that they are not located on loose sand fill and that adequately safe foundations can be provided.
- (3) Water supply lines and other utilities passing through loose sand fill are likely to be ruptured during a severe earthquake. Measures to ensure the continued supply of water and power and the continued functioning of sewage lines, should be explored.

In connection with the evaluation of liquefaction potential it should be noted that one of the most useful indices of the liquefaction potential of sand deposits is the "standard penetration resistance" which is normally determined during boring and sampling operations. Most of the past experience with regard to liquefaction has been related to this soil characteristic and it is highly desirable therefore that it be evaluated in detail and considered along with other pertinent factors (intensity of shaking, depth of water table, etc.) in evaluating the liquefaction potential of the soils at the island.

3. The old buildings on the base, built before 1933, may be quite hazardous in the event of strong shaking. These buildings should be studied to determine whether their continued use represents an acceptable risk.
4. The large above-ground storage tanks probably represent a severe fire hazard to the base and the surrounding area in the event of a major earthquake. The tanks should be investigated, and steps taken to reduce the fire hazard in the event of tank rupture or failure of connecting piping. In this regard it should be noted that standard methods of design of such storage tanks have not in the past given the earthquake protection desired. (See the above-mentioned Alaskan earthquake report, for example.) Also, the hillside site may not be stable during strong shaking.
5. The arch-ribbed hangars, built around 1935 following a German design, may possibly represent a hazard during strong shaking, although they probably have a higher degree of resistance than other reinforced concrete structures of that time. Their successful earthquake performance cannot be assumed, however, without examination. One might question, for example, whether the structures have sufficient shear resistance and ductility to resist strong longitudinal motions.
6. Fire-fighting equipment, including watertanks and building structures, should be checked to insure that they can survive a major earthquake without loss of function. In particular, preventive measures may be needed to make certain that rupture of waterlines does not cause loss of fire-fighting capability.
7. Any structure deemed by the Navy to be so important that it must survive strong ground shaking without loss of function should be studied in detail. In addition to the structure, particular attention must be given to nonstructural features, utilities, and standby power.
8. If the collapse of the Coronado bridge represents a serious operational problem to the Navy, they should inquire of the State Highway

Department or the appropriate control agency for the bridge as to the seismic safety of the structure. In particular, if the bridge is hazardous, they should urge that the bridge be strengthened in a manner similar to the program the State Highway Department is implementing for the most hazardous of its existing structures.

9. The Navy is now building or designing at least two major hospitals in the San Diego area. The design personnel should be made aware of the new provisions of the law of the State of California regarding seismic design of hospitals, and should see that the hospitals meet these new requirements to the extent possible. In particular, can the building now under construction be strengthened to meet these requirements if it does not now do so?
10. A study should be made of the effect of previous tsunamis in the San Diego area, especially the effects of tsunami-generated currents in the bay, and the current-induced effects on ship moorings, etc.
11. The Navy should consider portions of their facilities nearly as critical as is the case for the siting, design, construction and operation of a nuclear power plant. Thus, the type of tsunami studies that have been made for the San Onofre Nuclear Power Plant should be made for NAS North Island and the other low-lying naval facilities in the San Diego Bay area.

One step in this direction can be to use the tide records taken during tsunamis for San Diego and La Jolla of the type reproduced in References 6, 10, 16 and 20. These records plus others that can be obtained from the U. S. Coast and Geodetic Survey of NOAA (Department of Commerce) should be used to develop a tsunami distribution function for San Diego in the manner used by Wiegel (Reference 19) for other locations. This type of a distribution function should then be combined with the type of work of Petruskas and Borgman (Reference 15) to develop a distribution function of the combined occurrence of tides and tsunamis.

There is the possibility of a tsunami being generated offshore from San Diego, say by a strike slip tectonic displacement resulting in a

rather rapid change in bottom topography. Tsunami wave periods associated with this type of source are short, of the order of one minute or so (see Reference 9 by Garcia). Tsunamis of this type should be studied in a manner similar to that done by Whalin et al., (Reference 17).

12. Since the "draw-down" of a tsunami is equal to its run-up, the Navy should study the effect of different probable "draw-downs" on a moored ship striking bottom, and on water-side facilities that no longer have the design hydrostatic force acting on the bay side of the structure (such as a quay wall).
13. The possibility of fuel being released from storage tanks and pipelines is of considerable importance. The movement of such a spill by tsunami, tidal and wind currents should be estimated. Control and clean-up devices should be engineered into the facility.
14. Studies should be made of the possibility of earthquake-induced underwater slumps into dredged (or natural) navigation channels, to determine the likelihood of such occurrences and how they might affect the navigation of aircraft carriers and other large ships.
15. Consideration must be given to the use of the Tsunami Warning System that exists for the Pacific Ocean Area for tsunamis generated at sufficient distances from San Diego that they can be effective.
16. The new construction program currently envisaged for North Island should include adequate consideration of earthquake-resistant design procedures, with appropriate consideration being given to the function of the structures, their operational importance and the degree of risk the Navy is willing to accept in relation to each structure.
17. Our understanding of the seismicity of the San Diego region and adjacent offshore areas is so minimal that the ONR should continue



Mr. John G. Heacock  
November 1, 1973  
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to support the telemetry of seismic signals from stations in this area. For example, the existing station on San Clemente Island is generating information of unique interest to the Navy in terms of its investment in facilities on this island and intensive operations nearby.

We trust these observations will be helpful to your evaluation program.

Very truly yours,

C. R. Allen  
P. C. Jennings  
R. L. Wiegel  
H. Bolton Seed

HBS/nh

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H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

December 15, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

Most of the U. S. Navy facilities in the San Francisco Bay Area can be expected to be subjected to strong shaking from at least one earthquake during their economic life. Since none of the facilities appears to be underlain by a major fault, the major seismic hazards will undoubtedly be related to strong shaking resulting from earthquakes generated along the San Andreas, Hayward and Calaveras fault systems. The shaking may in some cases damage the facilities directly, the extent of damage depending on the type of structure involved and the degree of earthquake-resistance incorporated in its design. In other cases, damage may occur from ground failures produced by the strong shaking, involving such phenomena as settlement, liquefaction and landslides.

While it is not possible to assess the possible vulnerability of structures without an on-site inspection, a general assessment of the possible effects of strong shaking on the foundation soils can be made from a knowledge of their general characteristics. A brief survey of the foundation conditions at Naval facilities in the Bay Area is presented below.

#### Treasure Island

Treasure Island is located about 10 miles from the San Andreas fault and 7 miles from the Hayward fault. It is composed of dredged

fill, mostly sand with some clay inclusions, underlain by San Francisco Bay mud. It seems likely that some liquefaction of the sand fill would occur, with associated settlement and lateral displacements, in the event of a major earthquake.

#### Yerba Buena Island

Yerba Buena Island is located adjacent to Treasure Island but it provides excellent foundation conditions which are not likely to evidence any form of instability during a major earthquake.

#### San Francisco Bay Naval Shipyard (Hunters Point)

San Francisco Bay Naval Shipyard is located about 7 miles from the San Andreas fault and 11 miles from the Hayward fault. Large areas of the site (perhaps about 40 percent) appear to be constructed on sand fill with the remaining areas on soft clay. It seems likely that there will be some liquefaction and spreading of the sand fill during a major earthquake, together with some damage to long-period structures due to shaking.

#### Mare Island Naval Shipyard

Mare Island Naval Shipyard is located about 30 miles from the San Andreas fault and about 8 miles from the Hayward fault. An appreciable part of the island is underlain by stiff soils which would not show any signs of instability during earthquakes but other parts of the island are lowland areas, underlain by soft clays, which are protected by dikes. There is no information available concerning the stability of the dikes and there would seem to be a good possibility that slumping of some sections of these dikes would occur during a major earthquake.

#### Naval Supply Center, Oakland

The Naval Supply Center in Oakland is located about 14 miles from the San Andreas fault and about 7 miles from the Hayward fault. The site is covered by fill, partly sand but mostly clay, placed over San Francisco

Mr. John G. Heacock  
December 15, 1973  
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Bay mud. Because of the extent of the clay deposits, liquefaction would not be expected to be a major problem at this site. However the clay deposits are likely to lead to large amplitude displacements which could be damaging to long period structures and to underground utilities.

Moffett Field

The Moffett Field N.A.S. is located about 9 miles from the San Andreas fault and 9 miles from the Hayward fault. The foundation conditions are not clearly defined but they appear to consist mostly of clay with a relatively thin layer of Bay mud (10 to 30 ft thick) overlying stiffer soils. There would not appear to be any problem of liquefaction due to strong shaking but there may be some cracking and distortion of runways together with severe shaking of buildings.

I trust these observations will be helpful to your evaluation program.

Sincerely yours,

H. Bolton Seed

HES/nh

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H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

December 28, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

On November 1, 1973 an Advisory Panel consisting of Clarence R. Allen, Paul C. Jennings, Robert L. Wiegel and myself visited the Naval Weapons Center at Concord, California and the Navy communications facility at Skaggs Island, California to make a preliminary assessment of the potential damage which might occur to these facilities in the event of a major earthquake in the San Francisco Bay Area and formulate general recommendations for research which should desirably be conducted by the Navy to minimize the potential hazards. The inspection consisted of a briefing followed by a bus and walking tour of typical structures and facilities.

Our general impressions and recommendations resulting from the inspection are presented below.

Concord Naval Weapons Center

1. There is no evidence that this facility is directly underlain by faults which might cause a problem in terms of large earthquakes or in terms of surface displacements, and the seismic hazard to the center is determined primarily by possible earthquakes generated by the San Andreas fault, some 30 miles to the west, the Hayward fault about 16 miles to the west, and the Calaveras fault about 6 miles to the west. Possible earthquakes on these faults might be expected to occur with the following approximate frequencies:

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<u>San Andreas Fault</u>		<u>Hayward &amp; Calaveras Fault System</u>	
<u>Magnitude</u>	<u>Recurrence Interval</u>	<u>Magnitude</u>	<u>Recurrence Interval</u>
8.3	≈ 200 years	7.5	≈ 500 years
8.0	100 to 200 years	7.0	100 to 500 years
7.5	60 to 150 years	6.5	50 to 100 years
7.0	50 to 100 years		

In addition there is some possibility of an earthquake occurring on the Concord fault about 2 miles west of the facility.

Thus it must be assumed that structures at the site could well be subjected to at least one major earthquake during their economic life.

2. The greater part of the facilities at the center are located on stiff soils although the docking area is located on deposits of soft silty clay (Bay mud) and peat varying up to 40 ft in thickness.
3. A small number of structures supported on fill overlying the Bay mud may experience some settlement and distortion as a result of lateral spreading of the fill or local failures of the mud during strong earthquake shaking.
4. The most severe tsunami in recent history in the Pacific Ocean was the 1964 Alaskan one. It was recorded on a tide gage at Benecia Harbor, and the tsunami wave height there was only 0.4 foot. It would be approximately the same at the Concord Naval Weapons Center.
5. Most of the structures at this station, including the special structures used to store high explosives, are of a type that generally possesses a high degree of earthquake resistance. There are two possible exceptions to this general observation: 1) There is at least one single-story industrial-type building of reinforced concrete construction that may not be sufficiently earthquake resistant, depending on the connections between the structural elements. (We did not examine the building, because work with high explosives was in



- progress.), 2) The steel water storage tanks, if they are of typical design, may not be able to withstand very strong shaking without losing their contents.
6. The biggest hazard from earthquakes to the facility may well be from earthquake-caused fires or, conceivably, explosions. Handling large quantities of high explosives is inherently somewhat dangerous, and if the earthquake occurs at an awkward time, or if handling equipment or storage racks are sensitive to shaking, it is quite possible that an accident could be triggered by strong shaking. It seems, therefore, especially important that the fire-fighting equipment such as storage tanks, water lines, emergency power for pumps, etc., be capable of withstanding the strong shaking and ground slump and settlements that would be expected at the facility in the event of a nearby major earthquake.
  7. The possibility of a failure of tanks storing oil and other inflammable fluids at nearby refineries should be considered. Currents could move this material to the ship loading site, with accompanying hazard. It is our understanding that some ships at the docks are always ready to leave and that the ships that are not ready to leave under their own power can be moved by tugs which are always "on the ready." This should be verified, however.

Our overall impression of the facility was that it is not particularly vulnerable in the sense that it would be difficult for ground shaking to put the facility out of operation for a significant time, and the loss of operation of the facility for a short time could be tolerated.

#### Skaggs Island

1. As for the Concord NWC, Skaggs Island is not underlain by any major faults but it could be subjected to very strong shaking by earthquakes occurring on the San Andreas fault, 24 miles to the west and about 2 miles from the Hayward and Calaveras fault systems.

2. The island is underlain by deep layers of soft clay (Bay mud) varying up to 80 ft thick. The ground surface is below sea level and is protected by a continuous dike, about 15 miles long and 7 ft high, built in the early 1900's. Without this levee the island would be subject to daily flooding. The dike provides about 2 ft of freeboard at high tide.
3. The buildings and other structures at this facility are of types such that serious structural damage from shaking appears unlikely, with the possible exception of the elevated water tanks. If the tanks are relatively full, and if they were not designed on a dynamic basis, then there is the possibility of trouble if the shaking is severe. Elevated water tanks have failed during earthquakes.
4. Although serious structural damage is relatively unlikely, there is a good possibility that nonstructural damage to partitions, mechanical and electrical equipment, standby power units, computers, etc., could occur to the extent that the facility could not continue to function after the earthquake. This type of damage will almost certainly happen to some degree at least unless special care has been taken to insure earthquake resistance. The interior of the buildings were not examined.
5. The greatest earthquake-related hazard at Skaggs Island is the danger of flooding a consequence of failure of portions of the dike due to strong shaking. No information is available concerning the construction of the dikes but in view of the construction materials locally available and the procedures generally used at the beginning of the century, it seems inevitable that some sections would slump 2 ft or more in the event of a major earthquake, thereby subjecting the island to inundation at high tide. The effect of such a dike failure and the extent of inundation it would produce should be investigated. It appears that the two critical buildings

on the island are on slightly raised sites, and may not be seriously affected by the flooding. However in one of the buildings the computer center and the emergency power source are in the basement and these could be rendered inoperative.

It would seem desirable to check the elevations of these structures in relation to water elevation statistics to determine the extent of risk to operation of the facilities. Consideration might be given to constructing supplementary dikes around these structures to provide increased protection against flooding due to failure of the perimeter dike system.

Very truly yours,

C. R. Allen  
P. C. Jennings  
R. L. Wiegel  
H. Bolton Seed

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H. BOLTON SEED  
138 WHITETHORNE DRIVE  
MORAGA, CALIFORNIA 94556

December 29, 1973

Mr. John G. Heacock, Director  
Earth Physics Program, Code 417  
Department of the Navy  
Office of Naval Research  
Arlington, Virginia 22217

Dear Mr. Heacock,

On June 8, 1973 Professor Clarence R. Allen who is a member of the ONR Seismic Review Panel visited the Subic Bay Naval Station in the Philippines for the purpose of making a preliminary assessment of the potential damage which might occur to the facility in the event of a major earthquake. The inspection consisted of a briefing followed by a tour of the base. Professor Allen also obtained some boring logs indicating soil conditions at the base which I have reviewed. On the basis of the information obtained from these sources we offer the following comments:

1. Although the seismicity at Subic Bay is not as great as that at points farther east in the Philippines, damaging earthquakes have occurred in the region within the historic record and the active Manila trench is only a few kilometers offshore to the west. In addition, truly great earthquakes are possible on the Philippine fault, which at its closest point is only about 75 miles from the base. This is about the same distance as Anchorage, where major landslides and severe damage occurred, from the causative fault of the Great Alaska earthquake of 1964.
2. A large part of the base is constructed on filled ground; very little is known about the history of filling, except that it is pre-World War II. The fill appears to be mainly sand which may

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well be vulnerable to liquefaction during strong earthquake shaking.

3. There is currently some lateral movement of the wharves in part of the Rivera Point area towards the adjacent bay, and the supporting piles are becoming noticeably tilted. It is likely that these incipient landslide movements would be greatly accelerated by strong earthquake shaking resulting in severe damage to the wharf.
4. Numerous mud flows and landslides occurred in the hills around the bay during the particularly heavy monsoon rains of July 1972. The heaviest landslide damage to structures was in the area of the officers' and enlisted men's family housing which for the most part is constructed on steep slopes about a mile southeast of the main base. The geology here, as elsewhere on the base, appears to be represented by a wide variety of bedded tuffs and volcanic agglomerates. While no geologic map of the base seems to have been made despite the concern over landslide problems, a Manila company has recently been commissioned to evaluate the landslide potential of the housing area.
5. Perhaps of greater concern than the family housing area is the fact that the tank farm is constructed in an area of equally steep slopes and contains many major tanks and interconnecting pipelines. Despite the slides which took place in this area during the 1972 monsoons, fortunately not damaging any major tanks or pipelines, there is no study being contemplated for this area comparable to that prepared for the family housing area. It seems possible that slides might also occur in this area in the event of an earthquake following a period of heavy rainfall. Should any of the tanks or pipelines rupture as a result of such sliding, the oil would flow into the harbor and present a major fire hazard. It seems desirable that a study of such possibilities should be initiated.

Mr. John G. Heacock  
December 29, 1973  
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We conclude from this brief study that from a geologic and foundation engineering standpoint there appears to be considerable potential for serious damage to occur at the base in the event of strong shaking resulting from a major earthquake and that a more detailed study of this possibility is warranted.

Very truly yours,

Clarence R. Allen

H. Bolton Seed

HBS/nh

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